

Air-Sea Fluxes from Synthetic Aperture Radar

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LONG-TERM GOALS

My long-term goal is the testing and refinement of a Monin-Obukhov and mixed-layer similarity-based method for the extraction of marine atmospheric boundary layer turbulence statistics from synthetic aperture radar (SAR)-derived wind speed imagery of the sea surface (first described in Young et al. (2000) and hereafter referred to as the SAR method). A plethora of SAR data is available from the Johns Hopkins University Applied Physics Laboratory (JHU/APL) in conjunction with the National Oceanic and Atmospheric Administration (NOAA) Storm Watch / Alaska SAR demonstration.

In addition, my research has transitioned from sole-source Office of Naval Research (ONR) funding to a cost-share between ONR and the National Aeronautics and Space Administration (NASA). My collaborators on my NASA grant are Pierre Mourad, Ralph Foster, and Matt Wyant of the University of Washington Applied Physics Laboratory (UW/APL). We have begun testing the SAR method on wind images of the Tropical Atmosphere-Ocean buoy array area as well as on wind images corresponding to SHOWEX.

Before this testing can proceed in earnest, we must address the following obstacle: Wind speeds statistics generated from identical SAR imagery by different parties can differ greatly. I will discuss this issue further in the Results section of this document.

Once we reach a consensus on how one generates wind speed imagery, we plan to address the following issues pertaining to the performance of the SAR method: 1. How do we best eliminate extraneous variance in the wind speed imagery (e.g., that due to oceanographic phenomena and speckle)?; 2. What is the proper sub-image size (i.e., over what area of wind speed imagery should we be applying the SAR method)?; 3. Will the presence of certain sea states affect the near-surface turbulence in such a way as to cause a breakdown of the SAR method (e.g., see Drennan et al. 1999)?; 4. Are we properly diagnosing the mixed layer depth (z_i) (which is imperative for the correct assessment of the turbulence statistics from the SAR method) from the SAR wind speed imagery? 5. Will unresolved pixel-to-pixel changes in the wind direction affect the SAR method?

OBJECTIVES

The objective of the research that I am reporting was to test the SAR method using a dataset of Radarsat-1 overpasses from off the east coast of the United States collected between October 1996 and March 1997 beyond that reported in Sikora et al. (2000). More specifically, I wished to analyze the

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14. ABSTRACT My long-term goal is the testing and refinement of a Monin-Obukhov and mixed-layer similarity-based method for the extraction of marine atmospheric boundary layer turbulence statistics from synthetic aperture radar (SAR)-derived wind speed imagery of the sea surface (first described in Young et al. (2000) and hereafter referred to as the SAR method). A plethora of SAR data is available from the Johns Hopkins University Applied Physics Laboratory (JHU/APL) in conjunction with the National Oceanic and Atmospheric Administration (NOAA) Storm Watch / Alaska SAR demonstration.					
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SAR method's performance in the calculation of the ratio of reference height (z) to Obukhov length (L) and the calculation of the kinematic buoyancy flux (B).

In addition, I sought to begin similar testing on additional Radarsat-1 SAR images available from JHJU/APL in conjunction with the NOAA Storm Watch / Alaska SAR demonstration. These imagery are from off the east coast of the United States and the Gulf of Alaska.

APPROACH

Young et al. (2000) proposed and demonstrated a method to calculate diabatic wind speed and turbulence statistics from neutral wind speed imagery (Thompson and Beal, 2000) generated from synthetic aperture radar (SAR) data. Their SAR method is based on Monin-Obukhov and mixed layer similarity theory (Panofsky and Dutton, 1984; Stull, 1988). It relates the ratio of the mean to standard deviation wind speed, from the SAR-derived neutral wind speed imagery, to the static stability of the atmospheric surface layer. The scaling parameters arising from this relationship provide a stability correction to the neutral wind speed imagery in an iterative fashion. See Young et al. (2000) for an in-depth review of their method.

Upon completion of the stability correction, several of the resulting statistics (L and friction velocity (u_*)) can be combined with an independent measure of the sea-surface virtual temperature (T_v) to provide an estimate of B :

The demonstration of the SAR method by Young et al. (2000) was accomplished using *in situ* turbulence data gathered during the second High Resolution Remote Sensing project as ground truth. The comparisons presented in Young et al. (2000) were for data collected during rather quiescent synoptic scale and statically unstable microscale atmospheric conditions (i.e., light winds and negative air-sea temperature differences).

Sikora et al. (2000) advanced the testing of the SAR method by expanding the environmental conditions to more baroclinic regimes. Sikora et al. (2000) relied on NOAA buoys to provide a means of ground truth and only investigated the performance of the SAR method in the calculation of L and the drag coefficient (C_d). Although NOAA buoys do not provide such turbulence statistics, they do provide enough *in situ* data for input into the bulk flux algorithm arising from Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) (Fairall et al. 1996). The TOGA-COARE bulk flux algorithm, therefore, provided the "ground truth" for comparisons presented in Sikora et al. (2000).

Unlike the Young et al. (2000) study, the work reported in Sikora et al. (2000) did not include spectral filtering of the neutral wind speed imagery prior to the generation of turbulence statistics. However, Sikora et al. (2000) smoothed the pixel size of the SAR imagery to 300 m. This choice of pixel size and smoothing arose from the study of Mourad et al. (2000), who found that doing so resulted in a close fit between the wind spectrum resulting from a SAR image and that developed using low-level turbulence measurements gathered from an aircraft flying over the imaged area.

WORK COMPLETED

I have met my research objectives mentioned above. That is, I have completed testing the SAR method using a dataset of Radarsat-1 overpasses from off the east coast of the United States between October 1996 and March 1997. More specifically, I analyzed the SAR method's performance in the calculation of the ratio of z/L and B . The results of this research are reported Sikora and Thompson (2002). Since that publication, I have begun testing the SAR method on additional wind speed imagery provided to me by JHU/APL.

RESULTS

In the course of the research conducted since the publication of Sikora and Thompson (2002), it became apparent that wind speed imagery generated from the same SAR image by different parties could be quite dissimilar. As evidence of this, see Figure 1.

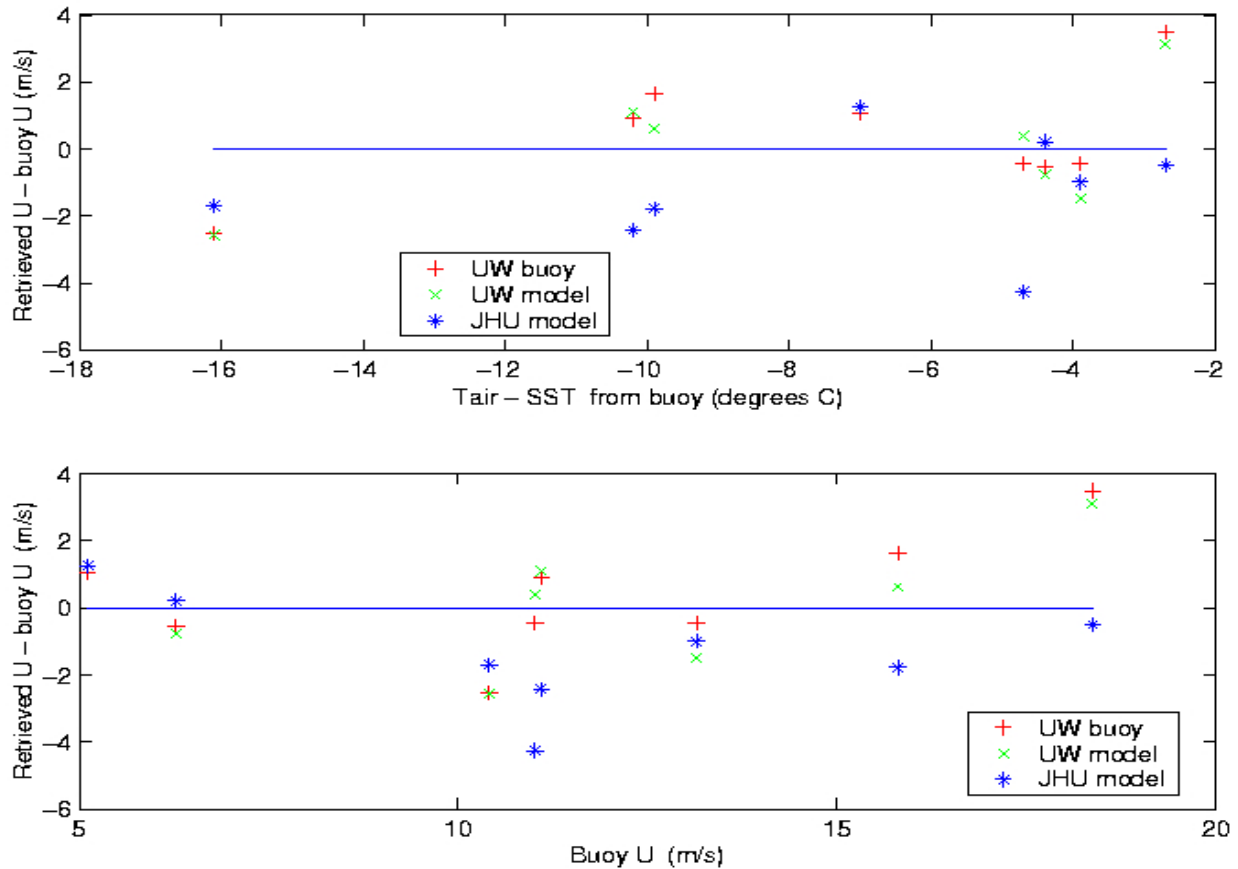


Figure 1: Wind Speed Comparisons

[Estimates of SAR-derived wind speed – buoy wind speed using three separate approaches: 1. UW/APL's algorithm using buoy wind directions (UW buoy); 2. UW/APL's algorithm using NOGAPS wind directions (UW model); 3. JHU/APL's algorithm using NOGAPS wind directions (JHU model) (Monaldo et al. 2001). The results are binned by air-sea temperature difference and buoy wind speed.]

Large differences between the results of each algorithm are evident for many of the cases. These results mimic, somewhat, the information presented at the SAR Wind and Waves Session of IGARSS 2002. Proper application of the SAR method requires first and foremost proper wind speed imagery. Thus, my colleagues and I are investigating the source of these differences. Sources of error that have been cited include wind direction, incident angle, calibration coefficients, image mapping, and polarization ratio.

IMPACT/APPLICATIONS

The research I have conducted thus far implies that the SAR method has the potential to provide accurate over-ocean flux measurements (by TOGA-COARE standards) at a very high resolution. Verification of the usefulness of this technique is important to the communities that would benefit from its implementation, such as those associated with synoptic-scale and mesoscale operational numerical weather prediction.

RELATED PROJECTS

As mentioned above, my research has transitioned from sole-source ONR funding to a cost-share between ONR and NASA. As part of my NASA research, I will be testing the SAR method on wind images of the Tropical Atmosphere-Ocean buoy array area as well as wind imagery from SHOWEX.

SUMMARY

A similarity theory-based method for calculating turbulence statistics from SAR-derived 10 m neutral wind speed imagery was tested using a dataset of Radarsat-1 overpasses from off the east coast of the United States between October 1996 and March 1997. I concentrated on its ability to yield proper estimates of the ratio of reference height to Obukhov length (z/L) and kinematic buoyancy flux (B) for a wind image sub-scene. My results are presented in Sikora and Thompson (2002).

In the course of the research conducted since the publication of Sikora and Thompson (2002), it became apparent that wind speed imagery generated from the same SAR image by different parties could be quite dissimilar. Proper application of the SAR method requires first and foremost proper wind speed imagery. Thus, my colleagues and I are investigating the source of these differences.

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Sikora, T. D., and D. R. Thompson, 2002: Air-sea turbulence statistics from synthetic aperture radar: An update. *Can. J. Remote Sens.*, **28**, 517-523.

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